CHAPTER 6.0: HYDROLOGICAL EFFECTS OF DEVELOPMENT IN ADDITION TO WATER USE

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GLOSSARY

Berm: A raised earthen area parallel to a stream, constructed for the purpose of containing the stream flow during periods of high water.

Canopy interception: The process whereby vegetation surfaces intercept a portion of the precipitation falling on a watershed. A portion of the intercepted water is evaporated back to the atmosphere during or after a storm event, thereby reducing the net precipitation reaching the soil.

Channelized: The modification of a natural river channel; may include deepening, widening, or straightening.

Consumptive (water) use: The loss of water from a ground- or surface- water source through a human-made conveyance system due to transpiration by vegetation, incorporation into products during their manufacture, evaporation, diversion, or any other process by which the water withdrawn is not returned to the waters of the basin undiminished in quantity.

Cutslope: The face of an excavated bank required to lower the natural ground line to the desired road profile.

DHSVM: Distributed hydrology-soils-vegetation model. Developed as a collaborative effort between hydrologists at the University of Washington and at Battelle Memorial Institute.

Dikes: A raised feature parallel to a stream, usually constructed of large rocks or boulders, built for the purpose of containing the stream flow during periods of high water.

Estuarine (wetlands): Tidal marshes that are semi-enclosed by land and have changing salinity levels due to interaction with the marine environment.

ET: See Evapotranspiration.

Evapotranspiration: The scientific term which collectively describes the natural processes of evaporation and transpiration. Evaporation is the process of releasing vapor into the atmosphere through the soil or from an open water body. Transpiration is the process of releasing vapor into the atmosphere through the pores of the skin of the stomata of plant tissue. By this process vegetation removes moisture from the soil profile and returns it to the atmosphere.

Floodplain (100- and 500-year): The floodplain is a flat area of land adjacent to a stream that stores and dissipates floodwaters. The 100-year floodplain is the area that is inundated during a flood having an average 100-year recurrence interval. The 500-year floodplain is the area that is inundated during a flood having an average 500-year recurrence interval.

Glacial outwash: Areas of sand and gravel that has been transported by streams of water coming from glaciers. It is highly permeable.

HSPF: Hydrologic Simulation Program - Fortran. A continuous watershed simulation model designed to simulate all the water quantity and water quality processes that occur in a watershed, including sediment transport and movement of contaminants. HSPF has its origin in the Stanford Watershed Model. Revisions to the model are currently under the purview of the Environmental Protection Agency (EPA).

Hydrography: The science which deals with the measurement and description of the physical features of the oceans, seas, lakes, rivers, and their adjoining coastal areas, with particular reference to their use for navigational purposes.

Interception: See Canopy interception.

Intertidal: The near-shore zone above low-tide mark.

Lacustrine: Pertaining to or associated with lakes.

Levees: An embankment for preventing flooding.

Limnetic: Of, relating to, or inhabiting the open water of a body of freshwater.

Littoral: Of, relating to, or situated or growing on or near a shore.

Mass wasting: Movement of soil and surface materials by gravity. Often synonymous with landsliding.

National Wetland Inventory: The National Wetlands Inventory is an inventory of wetland ecological systems found throughout the United States. It was prepared by the U.S. department of the Interior, Fish and Wildlife Service. The wetlands were identified on aerial photographs based on vegetation, visible hydrography, and geography in agreement with systems defined in Classification of Wetlands and Deep-Water Habitats of the United States, by Cowardin et al 1977.

Nisqually Resource Management Plan: An agreement developed in 1989 between four major forest landowners in the Nisqually River basin (Weyerhaeuser, Champion international, the Washington Department of Natural Resources, and the University of Washington Pack Forest), the Nisqually Indian Tribe, the regulatory division of the Washington Department of Natural Resources, the Washington Department of Fish and Wildlife, the Washington Department of Ecology, the Washington Environmental Council, the Washington Farm Forestry Association, and the Nisqually River Council. The Nisqually Resource Management Plan (NRMP) includes 92,000 acres of commercial forestlands in the mid-Nisqually River basin. The overall objective of the NRMP was to build consensus among all parties on long-term forest management to protect and enhance natural resources for the public.

NRMP: See Nisqually Resource Management Plan.

NWI: See National Wetland Inventory.

Outfall: The outlet of a storm drain or sewer.

Palustrine wetland: Freshwater, shallow wetlands that are not riverine or lacustrine, such as marshes or bogs.

Rain-on-snow: Wintertime weather conditions when relatively warm wind and rain combine to produce rapid snowmelt.

Recurrence interval: Also referred to as return period, is the average time, usually expressed in years, between occurrences of hydrologic events of a specified type or size. The terms "return period" and "recurrence interval" do not imply regular cyclic occurrence. The actual times between occurrences vary randomly, with most of the times being less than the average and a few being substantially greater than the average. For example, the 100-year flood is the flow rate that is exceeded by the annual maximum peak flow at intervals whose average length is 100 years (that is, once in 100 years, on average). The recurrence interval for annual events is the reciprocal of the annual probability of occurrence. Thus, the 100-year flood has a 1-percent chance of being exceeded by the maximum peak flow in any year.

Riverine: A freshwater system associated with a river; riverine wetlands are those that occur within the river channel and are dominated by emergent vegetation that remains only through the growing season.

Road density: A measure of the quantity of roads within a given area of land. Usually represented in units of miles of road/mi2 watershed area.

ROS: See Rain-on-snow.

Side-cast road: Road constructed by moving excavated material onto the downslope side of the road surface during its construction.

Snowpack: The total snow and ice on the ground, including both the new snow and the previous snow and ice that have not melted.

Stormwater discharge: Precipitation that does not infiltrate into the ground or evaporate due to impervious land surfaces but instead flows onto adjacent land or water areas and is routed into drain/sewer systems.

Subtidal: The near-shore zone below low-tide mark

TIA: Total impervious area. A measure of the total amount of area within a watershed with the ability to repel water, or not let water infiltrate.

WRIA: Water Resource Inventory Area. Administrative and planning units that encompass large river basins. There are 62 WRIAs within the state of Washington.

CHAPTER 6.0: HYDROLOGICAL EFFECTS OF DEVELOPMENT IN ADDITION TO WATER USE

INTRODUCTION

There are several pathways through which stream flows can be affected by land use in addition to the direct consumption of water (Figure 6-1). The primary agents of effect on hydrology (besides direct consumptive use) are:

- The interception of flow as a result of road construction and other land grading activities,
- Increases in impervious area,
- Changes in floodplain storage capacity,
- Change in wetland function,
- Alterations of channel capacity, and
- Modification of vegetative cover.

These potential effects are discussed in this section. Note that the effects from water use and regulation are not included in this section as they are covered elsewhere. For subbasins where the non-consumptive land-use effects on water quantity are potentially significant, we have identified an approach to quantifying changes in Chapter 7.0 (Data Gaps and Recommendations).

OUTFALL FROM ROAD DRAINAGE

Road networks have the potential to affect watershed hydrology by changing the pathways by which water moves through the watershed (WFPB, 1997). Road networks affect flow routing by interception of subsurface flow at the road cutslope (Megahan 1972, Burroughs et al. 1972, King and Tennyson 1984, Best et al. 1995) and through a reduction in road-surface infiltration rates resulting in overland flow (Ziemer 1998). The net result may be that surface runoff is routed more quickly to the stream system if the road drainage network is well connected with the stream channel network.

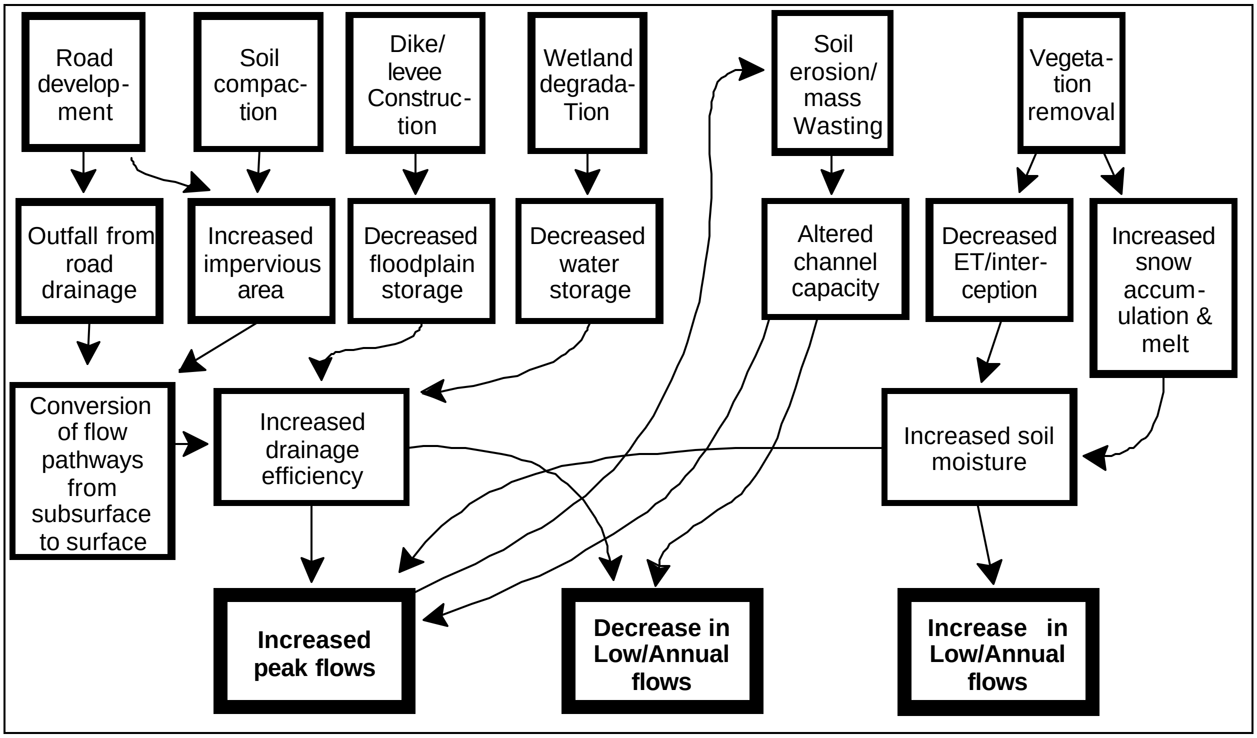

Figure 6-1. Generalized diagram of the primary interactions between land uses found in the lower Nisqually Basin and changes in peak, annual, and low stream flows (after Ziemer, 1998).

Connectivity of the road drainage and stream channel networks was qualitatively assessed in the Mashel subbasin as part of the Mashel Watershed Analysis (WDNR, 1996). The analyst made the following observations (for roads in the upper portions of the subbasin), which illustrate the potential for existing road drainage networks to significantly alter the way water flows through the drainage:

- An extensive road network exists, with numerous stream crossings (and mid-slope roads),
- Many ditches on mid-slope roads have flowing water during dry conditions (mid-September, 1995),
- There are generally large distances between culverts (approximately 1000 ft) coupled with routing of road surface and ditch water runoff directly into perennial and ephemeral channels.

The analyst estimated that the road drainage network in the upper Mashel subbasin resulted in a 14 to 35 percent increase in the effective drainage network. The analyst hypothesized that this increase in the effective drainage network may potentially increase peak flows by routing stormflow more quickly to the stream system, and potentially reducing summer low flows. No estimates were made on the magnitude of these effects on either peak or low streamflows.

The Yelm Creek Comprehensive Management Plan (Tetra Tech / KCM, 2001) identified only one storm water outfall to Yelm Creek in the Yelm subbasin, and no assessment was made of its contribution to peak or low/annual streamflows. Thurston County (1993) reports that no major stormwater outfalls exist along McAllister or Little McAllister Creeks in the McAllister subbasin. No additional studies on the effects associated with conversion of flow paths from surface to subsurface via outfall from road drainage are available for other areas within the lower Nisqually Basin. However, given the characteristics of the lower Nisqually Basin (i.e., low-relief, deep glacial outwash material) it is unlikely that this effect is significant in other portions of the watershed.

Spatially distributed, physically based models have been used to simulate the effects of forest road drainage networks on streamflows. In two studies located in the nearby Deschutes River basin (WRIA 13), Bowling and Lettenmaier (1997) and La Marche and Lettenmaier (1998) used a distributed hydrology-soils-vegetation model (DHSVM) to evaluate the effects of forest road systems on peak streamflows. In the event that the Planning Unit wished to further evaluate the effects of road drainage networks on stream flows in the Mashel subbasin we would recommend using a similar approach.

INCREASED IMPERVIOUS AREA

Increases in the amount of impervious area in a watershed result in increased peak flow magnitudes by eliminating or reducing infiltration of precipitation, thereby shortening the travel time to stream channels (Dunne and Leopold, 1978). In addition to the effects on peak flows, increases in impervious area also reduce summer low flows by reduction of groundwater recharge (Dunne and Leopold, 1978). May and others (1997), in a summary of several previous studies (Klein, 1979; Steedman, 1988; Schueler, 1994; Booth and Reinelt, 1993), suggest that impairment begins when percent total impervious area (%TIA) in a watershed reaches 10%. May and others (1997) recommend that for Puget Sound lowland streams, the level of imperviousness should be limited to the <5%-10% TIA, unless extensive riparian buffers are in place.

The only assessments of watershed imperviousness available in the lower Nisqually Basin are for the McAllister subbasin (Thurston County, 1993), and portions of the Muck/Murray subbasin (Pierce County, 2000). In the McAllister subbasin it was noted that no major flooding problems exist due to the largely undeveloped character of the subbasin. In the Muck/Murray subbasin land use maps were assigned a value for imperviousness based on development type. The assessment came up with an average of 7% impervious area.

May and others (1997) developed a relationship between % TIA and road density (expressed in miles of road/mi^2 watershed area). Watershed %TIA of 5% and 10% equates to a road density of 4.2 and 5.5 mile/mi^2 respectively. Road density was calculated for each subbasin in the lower Nisqually Basin using road data from the U.S. Bureau of the Census (US Bureau of the Census, 2001). The Toboton/Powell/Lackamas subbasin has the highest road density (4.2 miles/mi^2; Table 6-1), which corresponds to a %TIA of approximately 5%.

Table 6-1. Road density by subbasin. Data Source: US Bureau of the Census (2001).

Subbasin	**Road length (miles)**	**Subbasin area (mi^2)**	**Road density (miles/mi^2)**
1. McAllister	144.6	39.2	3.7
2. Muck/Murray	597.9	181.5	3.3
3. Yelm	204.6	52.0	3.9
4. Toboton/Powell/Lackamas	116.4	27.8	4.2
5. Tanwax/Kreger/Ohop	284.8	82.1	3.5
6. Mashel	260.7	89.2	2.9
Total for Lower Nisqually Basin	**1,609.1**	**471.8**	**3.4**

Based on the above information it appears that, at the subbasin level, percent impervious area, and its possible impacts to peak and low flows, is not a significant concern in the lower Nisqually Basin. However, concerns may exist in smaller subbasins. For example, the results from Pierce County (2000) indicate that in a portion of the Muck/Murray subbasin the percent impervious area may be 7%. Streamflow modeling has been done in King County (e.g., Booth and Reinelt, 1993; Booth and Jackson, 1997) to assess the impacts of urbanization (including %TIA) using the HSPF model (USEPA, 1997). A similar modeling exercise may be considered for certain areas of the lower Nisqually Basin if concerns regarding the potential effects of impervious areas increase in the future.

DECREASED FLOODPLAIN STORAGE

Dikes and levees have been constructed in several locations within the lower Nisqually Basin for flood control purposes. Potential disadvantages to dikes and levees include loss of floodwater storage within the floodplain, which can result in higher downstream peak flows, reduced groundwater recharge and subsequently lower summertime base flows. Digital data on locations of the 100- and 500-year[1] floodplains within the lower Nisqually Basin are available from the Federal Emergency Management Agency (FEMA, 1996). Significant portions of all subbasins are within the 100-year floodplain (Table 6-2).

Table 6-2. Percent subbasin area within the 100- and 500-year floodplains. Data source: FEMA (1996).

Subbasin	% Subbasin area	
	100-year floodplain	Additional area within the 500-year floodplain*
1. McAllister	10.7%	4.2%
2. Muck/Murray	6.3%	3.7%
3. Yelm	3.7%	0.4%
4. Toboton/Powell/Lackamas	9.9%	0.8%
5. Tanwax/Kreger/Ohop	6.8%	3.0%
6. Mashel	2.2%	0.2%
Total for Lower Nisqually Basin	**8.0%**	**2.4%**

* The values show for the 500-year flood plain are the additional areas beyond the 100-year floodplain. The 500-year also includes the 100-year floodplain shown in the preceding column

The length of stream within the lower Nisqually Basin that is affected by dikes and levees has not been quantified, but it is relatively low compared with other Puget Sound river systems (Nisqually EDT Workgroup, 1999). Virtually the entire mainstem of McAllister Creek has been diked (Thurston County, 1993). The most significant dikes are in the vicinity of I-5, where the creek was relocated through an approximately ½ mile long reach. Tetra Tech / KCM (2001) identified several portions of Yelm Creek between Crystal Springs Road and Bald Hills Road (from approximately RM 2 to RM 4) that have berms along the banks. Both Tanwax and Ohop Creeks have had several miles of their mainstem channelized in the past for flood control purposes (Nisqually EDT Workgroup,

[1] FEMA's Q3 flood data specifications indicates that areas mapped as the 500-year floodplain include areas inundated by 500-year floods, areas inundated by 100-year floods with average depths of less than 1 foot or with drainage areas less than 1 square mile, or areas protected by levees from 100-year flooding.

1999). The only significant dikes in the Mashel subbasin are along an approximately one-mile section through the City of Eatonville (WDNR, 1996).

DECREASED WETLAND FUNCTION

Wetlands have the ability to intercept and store storm runoff; thereby reducing peak flows (Mitsch and Gosselink, 1986). This water is released over time and may be important to augment summertime low flows. No studies are available for the lower Nisqually Basin quantifying the role of wetlands in ameliorating flood peaks and/or augmenting low flows, or identifying land use impacts to these functions. Data on wetlands in the lower Nisqually Basin are available from four different sources.

National Wetland Inventory (NWI) data is available in digital format for the entire lower Nisqually Basin (USFWS, 2001). Attribute information for NWI data in the lower Nisqually Basin includes wetland class (i.e., marine, estuarine, riverine, lacustrine, palustrine), sub-system (e.g., subtidal, intertidal, limnetic. littoral), class (e.g., emergent, scrub-shrub, forested, open water), water-regime (e.g., temporarily flooded, seasonally flooded, permanently flooded), and a special modifier indicating the level of disturbance (Cowardin and others, 1979). The special modifiers indicating disturbance include impoundments created by beavers, wetlands that are partially drained or ditched, wetlands influenced by dikes or impounded by human activity, and wetlands that have been excavated.

Both Thurston and Pierce Counties have digital wetland data available. The Thurston County data set is from two different sources; the NWI and data developed by the Thurston Regional Planning Council from a low level inferred flight in 1991. The Thurston County data set uses the same attribute coding system as the NWI (described above). The Thurston County data set identifies 12.3 mi^2 of wetlands in the Thurston County portion of the lower Nisqually Basin (i.e., the McAllister, Yelm, and Toboton/Powell/Lackamas subbasins), which is 11% greater than the 11.1 mi^2 of wetlands identified in the NWI.

The Pierce County data set was created from paper maps that had wetlands drawn on them over the years from various sources in the Pierce County Planning department. Source maps included tax maps, NWI maps, and Pierce County wetlands biologist maps. No attribute information is included in the digital data set. The Pierce County data set identifies 26.4 mi^2 of wetlands in the Pierce County portion of the lower Nisqually Basin (i.e., the Muck/Murray, Tanwax/Kreger/Ohop, and Mashel subbasins), which is 24% greater than the 21.3 mi^2 of wetlands identified in the NWI.

The final source of wetland information available in the lower Nisqually Basin is from the Nisqually Resource Management Plan (NRMP) Wetland Inventory (Sargent and Salminen, 1996). The NRMP Wetland Inventory covered 143 mi^2 of commercial forestlands, 129 mi^2 of which were located within the lower Nisqually Basin. Lands included in the inventory were owned by Weyerhaeuser, Champion International (now The Campbell Group), the Washington Department of Natural Resources, and the University of Washington Pack Forest. Wetland areas were identified using aerial photographs, NWI maps, soil surveys, and field reconnaissance. All wetland areas larger than 10 acres were field verified, and a portion of the wetlands smaller than 10 acres were also verified. The wetland acreage identified in the inventory was more than twice that identified by the NWI for the same area.

The NWI, despite the fact that it under-represents actual wetland area (as discussed above), is the single common source of data for characterizing wetland disturbance in the entire lower Nisqually Basin (Table 6-3). Consequently, the NWI was used as an index of wetland disturbance that may be affecting peak and low stream flows in the lower Nisqually. Areas modified by human activity include wetlands that have been partially drained or ditched, wetlands that have been impounded by human activity, and wetlands that have been excavated.

The proportion of subbasin area made up by wetlands ranges from 1% in the Mashel subbasin to 12% in the McAllister subbasin (Table 6-3). The proportion of total wetland area modified by human activity ranges from a low of less than 1% in the Toboton/Powell/Lackamas and Tanwax/Kreger/Ohop subbasins to over 30% in the McAllister subbasin.

Table 6-3. Summary of wetland area in the lower Nisqually Basin, and wetland area modified by human activity. Data source: National Wetland Inventory (USFWS, 2001).

Subbasin	Subbasin area (mi^2)	Wetland area (mi^2)	% Wetland area	Wetland area modified (mi^2)	% Wetland area modified
1. McAllister	39.2	4.6	12%	1.47	32.3%
2. Muck/Murray	181.5	13.5	7%	0.85	6.3%
3. Yelm	52.0	3.9	8%	0.13	3.2%
4. Toboton/Powell/Lackamas	27.8	2.7	10%	0.01	0.3%
5. Tanwax/Kreger/Ohop	82.1	6.6	8%	0.04	0.6%
6. Mashel	89.2	1.2	1%	0.07	6.2%
Total for Lower Nisqually	**471.8**	**32.4**	7%	**2.57**	**7.9%**

ALTERED CHANNEL CAPACITY

Deposition of both coarse and fine sediments in stream channels can result in a decrease in channel conveyance capacity, leading to increased frequency of overbank flooding (Dunne and Leopold, 1978). In addition to the effects on peak flows, increases in aggradation of coarse sediments can increase the proportion of streamflow that travels subsurface, resulting in a reduction of effective summer low flows. Many of the processes described in preceding sections result in increased peak flows, which can further exacerbate sedimentation problems through increased bank erosion and mass wasting.

Thurston County (1993) identified severe erosion problems in Little McAllister Creek in the area where the creek descends to the Nisqually River valley. The source of this erosion was identified as higher stream velocities due to upstream wetland ditching and development. Deposition from the eroded areas occurs in the vicinity of the confluence of Little McAllister and McAllister Creeks.

No information on sedimentation is available for the Muck/Murray subbasin. Sedimentation was investigated within the lower portion of Yelm Creek (from the mouth to approximately RM 4.5) as part of the Yelm Creek Comprehensive Flood Management Plan (Tetra Tech / KCM, 2001). The majority of Yelm Creek within this reach was identified as a sediment deposition area. The authors identified (but did not quantify) the sediment sources as being 1) sediments transported from upstream areas, 2) livestock trampling, 3) sedimentation in the vicinity of the stormwater outfall, and 4) sediment anchoring by reed canarygrass, a non-native, introduced species.

Sedimentation due to mass wasting and surface erosion was assessed for the Toboton/Powell/Lackamas and Tanwax/Kreger/Ohop subbasins as part of the Ohop/Tanwax/Powell Watershed Analysis (Nisqually Indian Tribe, 1998). Results from this study indicate that, relative to the adjacent Mashel subbasin, this subbasin was not very active in terms of mass wasting. Many of the landslides identified were ancient failures associated with the steep bluffs along the Nisqually and Ohop valleys. A number of shallow-rapid failures were identified, the majority associated with side-cast road construction or small failures on relatively steep slopes within clear-cuts. Few of these failures were found to deliver sediments to streams. There were no channelized debris flows identified during the assessment. Ravel failures, mostly associated with the Clay City mine (no longer in operation; located near the mouth of Twentyfive Mile Creek), generally did not deliver sediment to fish-bearing streams.

The surface erosion assessment for the Toboton/Powell/Lackamas and Tanwax/Kreger/Ohop subbasins (Ohop/Tanwax/Powell Watershed Analysis; Nisqually Indian Tribe, 1998) found that forest management activities have increased sediment delivery by less than the 50% within the subbasin. For the vast majority of the landscape, management activities do not appear to be the dominant factor in production and delivery of sediment. Factors contributing to the relatively low management-related sediment production and delivery within the subbasin included 1) generally stable deep soils, 2) low elevation and long growing season, 3) limited hill slope angle and length, 4) old road system appropriately maintained, and 5) low road traffic volumes. While management related sediment delivery was low, many channels were observed to have high levels of fine sediment. The analyst attributed this observation to erosion and remobilization of channel bed and bank material.

Sedimentation due to mass wasting and surface erosion was assessed for the Mashel subbasin as part of the Mashel Watershed Analysis (WDNR, 1996). The primary finding from this report was that roads and timber harvest had increased the frequency of mass wasting, resulting in increased sediment supply to streams, primarily in the upper watershed and the inner gorge of the Middle Mashel (upstream of Eatonville) and Lower Mashel (lower 4 miles of the river). Increased sediment load was found to be responsible for widened stream channels, resulting in reduced depth of flow in the summer. Past road-building and timber harvest within and adjacent to certain wetlands were found to have imported and/or remobilized sediment within the wetland, resulting in frequent occurrences of fine sediment transport to streams. The forest road system in the Upper Mashel, South Fork Mashel, and Upper Busywild areas was found to significantly increase fine sediment delivery to streams, potentially impacting downstream areas. Increases in sediment delivery were attributed to the high connectivity of the road system to channels.

The most significant recent sedimentation event to have occurred within the mainstem Nisqually River was the 1990 landslide that occurred approximately ½ mile downstream of the confluence of Ohop Creek and the Nisqually River. Approximately 200,000 m^3 of material was deposited in the river (Pringle, 1990). The major impact of this event in terms of peak and low streamflows appears to be associated with increased sediment deposition in the portion of the river from approximately RM 26-30 (Troutt, 1995).

VEGETATION REMOVAL EFFECTS

CHANGES IN PEAK FLOWS

Rain-on-snow (ROS) is the common term used to describe wintertime conditions when relatively warm wind and rain combine to produce rapid snowmelt (Coffin and Harr, 1992). Rain-on-snow flood events may occur in areas having significant wintertime snowpacks, and are independent of land use. Timber removal can augment ROS peak flows by increasing snow accumulation in openings (Troendle 1983; Bosch and Hewlett 1982) and increasing the rate of snowmelt by increasing the effective wind speeds at the snowpack surface (Harr 1981; Harr 1986; Coffin and Harr 1992).

The extent to which forest removal may augment ROS peak flows is a function of the amount of harvesting within the elevation range that defines the ROS zone. At low elevations (below the ROS zone) winter temperatures are generally too warm to allow for significant snow accumulation, and at higher elevations wintertime precipitation generally falls as snow. ROS peak flows are likely to be augmented by forest harvesting in Washington State in the 1,400 - 4,000 foot elevation range (WFPB, 1997).

None of the McAllister, Muck/Murray, or Yelm subbasins contain area that is considered to be in the ROS zone, consequently, these subbasins are considered to have a low sensitivity to augmentation of ROS peak flows by forest harvest.

Augmentation of ROS peak flows by forest harvest was assessed for the Toboton/Powell/Lackamas and Tanwax/Kreger/Ohop subbasins (Nisqually Indian Tribe, 1998) and the Mashel subbasin (WDNR, 1996). Predicted increases in the two-year recurrence interval peak flow (the peak flow most sensitive to ROS effects) under current forest canopy conditions were up to 3.4% in the Twentyfive Mile Creek tributary, and up to 2.7% in the Lynch Creek tributary (Nisqually Indian Tribe, 1998). Predicted increases in the two-year recurrence interval peak flow under current forest canopy conditions in the Mashel subbasin ranged from 3.9% to 13.3% among the 10 analysis units. These increases were not considered to be of sufficient size to merit special attention in the watershed analyses.

CANOPY INTERCEPTION / EVAPOTRANSPIRATION LOSS

Vegetation can intercept a portion of the precipitation falling on a watershed, a further portion of which is evaporated back to the atmosphere during or after a storm event, thereby reducing the net precipitation reaching the soil (Dunne and Leopold 1978). Evapotranspiration by vegetation removes moisture from the soil profile and returns it to the atmosphere (Dunne and Leopold 1978).

Increases in peak flows have been observed in some situations following harvest of trees, which are presumed to be the result of loss of canopy interception and evapotranspiration (Ziemer 1998). Several studies (Harr et al. 1979; Helvey 1980; Harr and Krygier 1972; Bosch and Hewlett 1982; Harr 1983; Hetherington 1987; Kattelmann et al. 1983; Troendle 1983; Keppeler 1998) have shown that water yield increases throughout the year, with the largest relative increases occurring during the summer and early fall months following logging. These studies have reported increases in summer flows ranging from 15 to 148 percent.

The changes in long term or season flows in the Nisqually basin associated with changes in canopy interception and/or evapotranspiration as a result of land clearing have not been evaluated. The results of studies conducted to date have been highly variable; hence no estimate of effects of land clearing in the watershed can be made at this time. The HSPF model or other methods could be used should the effects of changes in vegetative cover be identified as a concern.

SUMMARY

The review of land use impacts in the lower Nisqually Basin presented here is based on the results of existing studies and incorporates only minimal new analysis (e.g., the assessment of impervious area based on road density). It is limited to the information that is on hand and as such provides a very incomplete picture for the area. Most of the data provide a "snapshot" of conditions at the time that a given study was done (e.g., the NRMP wetland inventory), some is highly speculative (e.g., road drainage problems in the Mashel), and much of the data is not current (e.g., the NWI).

However, these limitations notwithstanding, the data and studies summarized here provide us with the means to make some limited conclusions about land use impacts in the lower Nisqually Basin, and help us identify the data gaps that limit further analysis.

Impacts from the outfall of road drainage on stream flows are probably not a significant issue in the lower Nisqually Basin, with the exception of the Mashel subbasin. Increased impervious area also does not appear to be a serious concern in the area at the present level of development. Increases in impervious area however may result in future problems assuming full build out. Decreased floodplain storage due to levees and dikes also does not appear to be a significant problem (with respect to stream flows) in the lower Nisqually Basin. Altered channel capacity due to sedimentation does appear to be a concern in some portions of the lower Nisqually Basin, although it is doubtful that current conditions have a significant effect on stream flows (sedimentation effects on fisheries however may be more significant). Neither the effects of loss in wetland storage (if any), nor the effects of vegetation removal on stream flows have been adequately assessed in the lower Nisqually Basin.